# Optimization of conjunctive water supply and reuse systems with distributed treatment for high-growth water-scarce regions

NSF EFRI – RESIN

$2M grant over 4 years

Emerging Frontiers of Research and Innovation

Resilient and Sustainable Infrastructures

# Participants

Kevin Lansey (CE)

Robert Arnold (Environ. Eng.)

Guzin Bayraksan (Systems Eng.)

Christopher Choi (Ag and Bio. Eng.)

Christopher Scott (Udall Public Policy)

Steve Davis (Malcolm Pirnie)

Doosun Kang (CE Post-Doc)

Majed Akhter

Alex Andrade

Ronson Chee

Kerri Jean Ormerod

Pierre Peguy

Pedro Romero

Anne Stewart

Gwen Woods

Weini Zhang

Several undergraduate students and MP staff

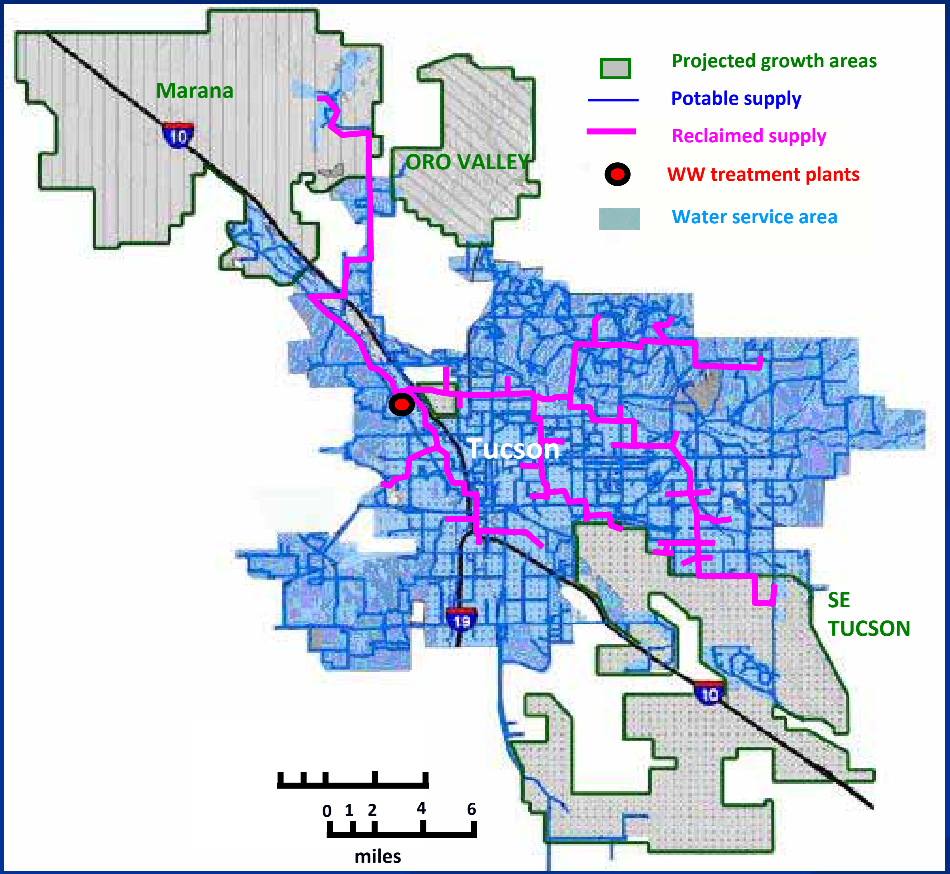
Brian Keller (graduated)

# Partners

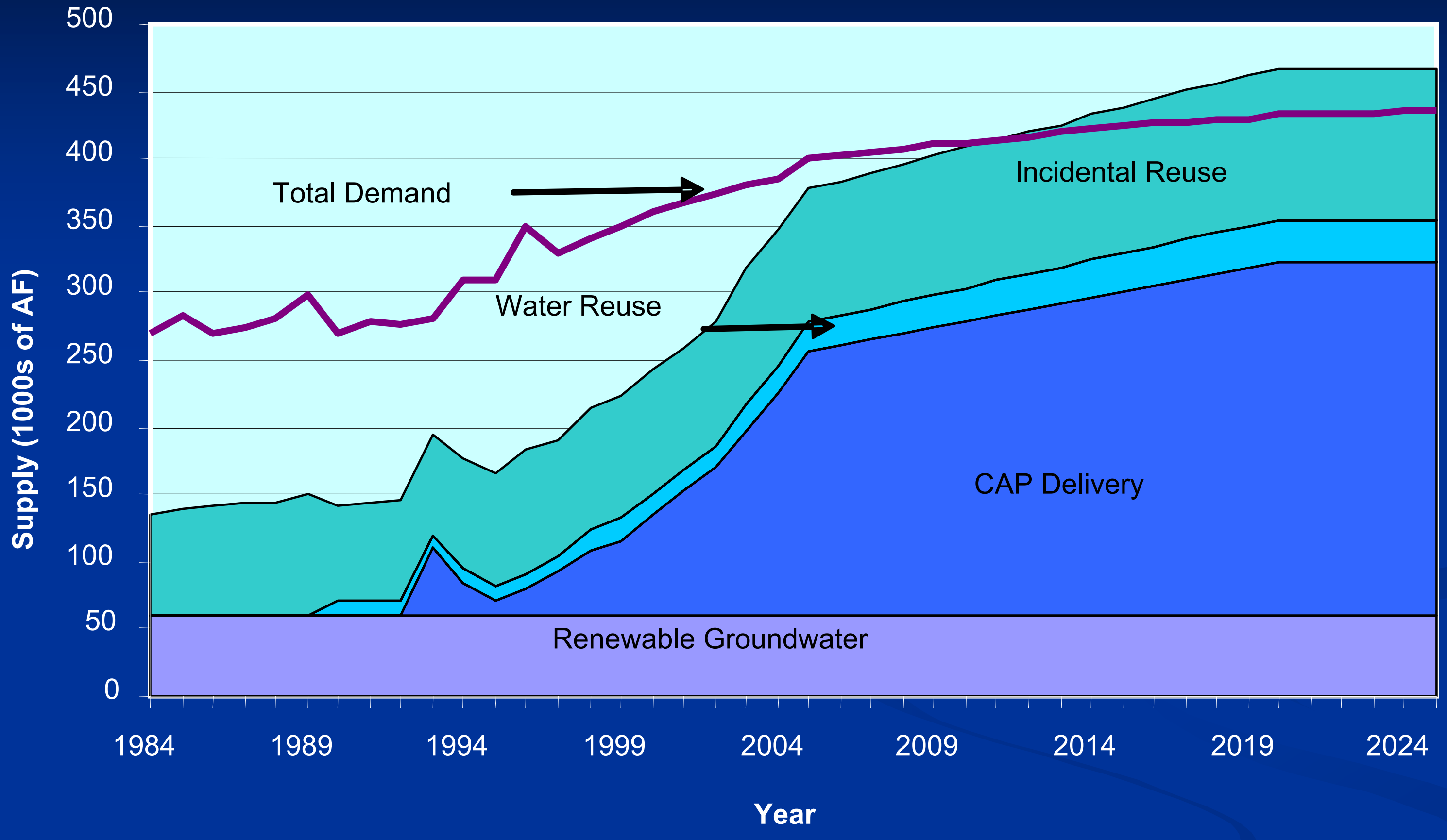
GLOBAL WATER
RELIABLE · RENEWABLE · REUSABLE

Pima County Department of Wastewater Management

TUCSON WATER



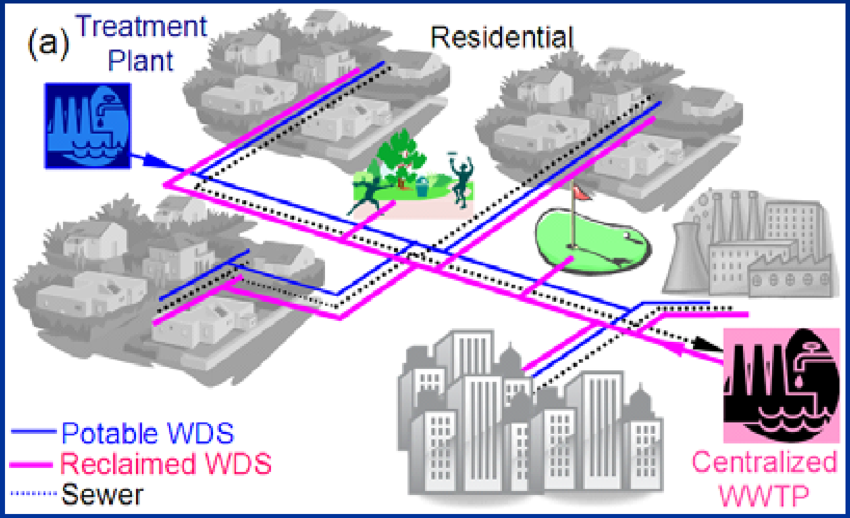
# The Problem



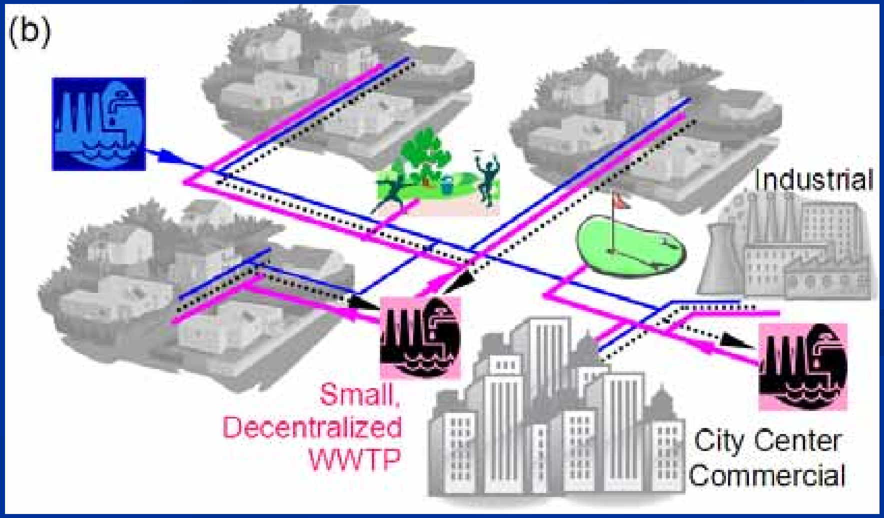

Historic and projected water demand in the Tucson Active Management Area (using data from City of Tucson (2004))

# Is water reclamation the next bucket?

## NAE grand challenge: “Combined neighborhood” of urban water and wastewater systems




Decentralized/satellite treatment -
- Where and how to treat?




Dual distribution systems -
- How to distribute and for what uses?

# Utility Goals

- Reliably satisfy water demand and water quality needs
- Triple bottom line objectives
    - Construction and operational costs
    - GHG and impact of releases to environment
    - Institutional/regulatory compliance and social acceptance
- All under an uncertain future

# Project Goals

Optimize real and randomly generated systems to analyze the effects of:

- institutional, legal and social constraints and
- topology and spatial land development patterns

on the optimal layout and design of integrated water supply/wastewater treatment services and assess

- the resiliency and sustainability of the system to withstand supply, energy and mechanical disruptions and
- the system objectives in terms of dollars, energy, and GHG production

Lansey & Choi

Model dual supply systems
- Hydraulics
- Economics
- Energy
- *GHG production*
- *Water quality*
- *Reliability*

Model regional supply systems
- Water Demands
- Economics
- Energy
- *GHG production*
- *Supply and Demand uncertainty*
- Quantify Resilience/sustainability

Arnold & Davis

Utility input & support

On the ground applications

Optimize dual supply systems

Bayraksan & Lansey

Optimize complete water reclamation/supply system

Optimize regional supply systems

Life cycle cost analysis

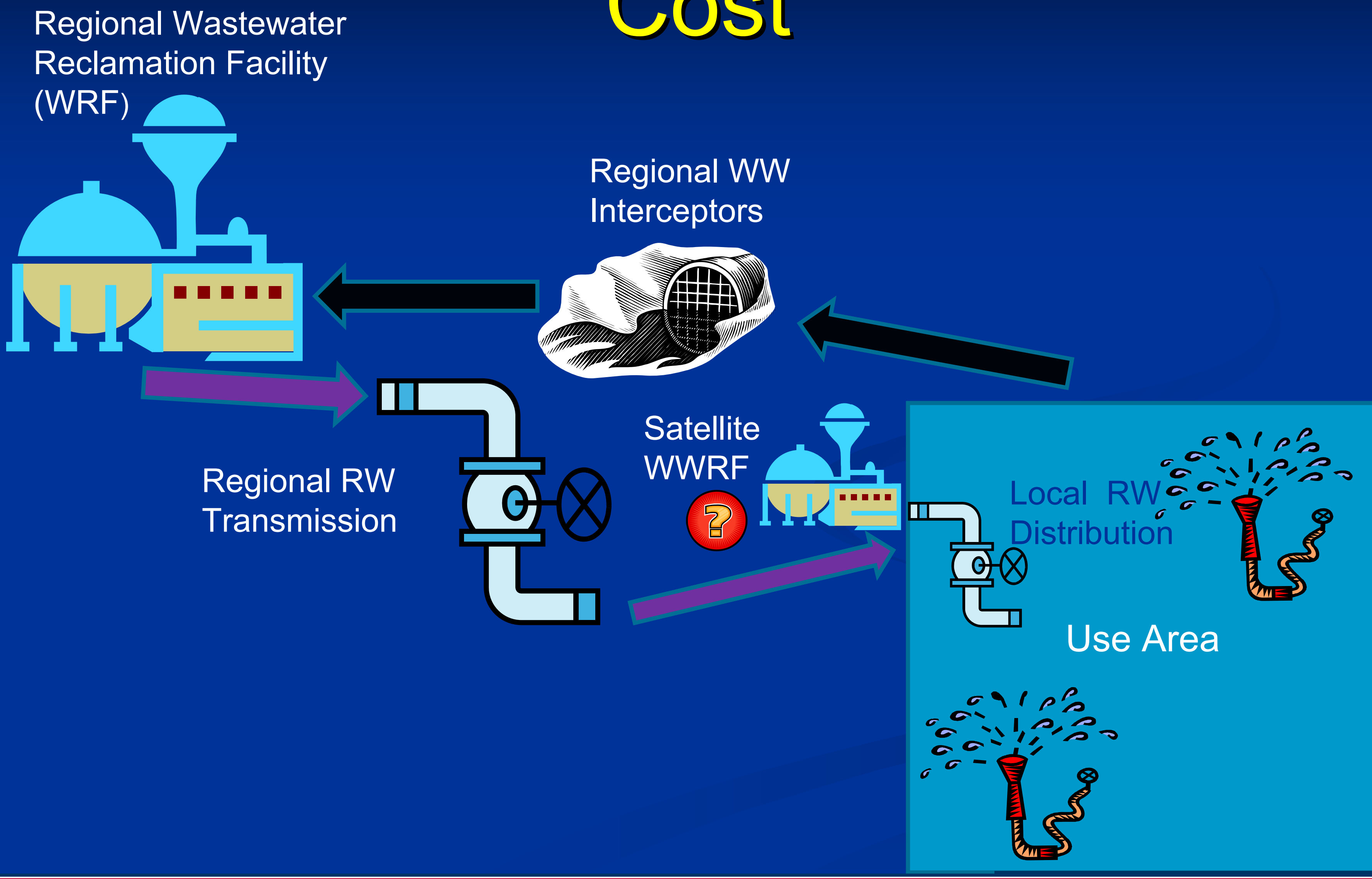
Assess social institutional, legal constraints and goals

Public education and utility tools

All

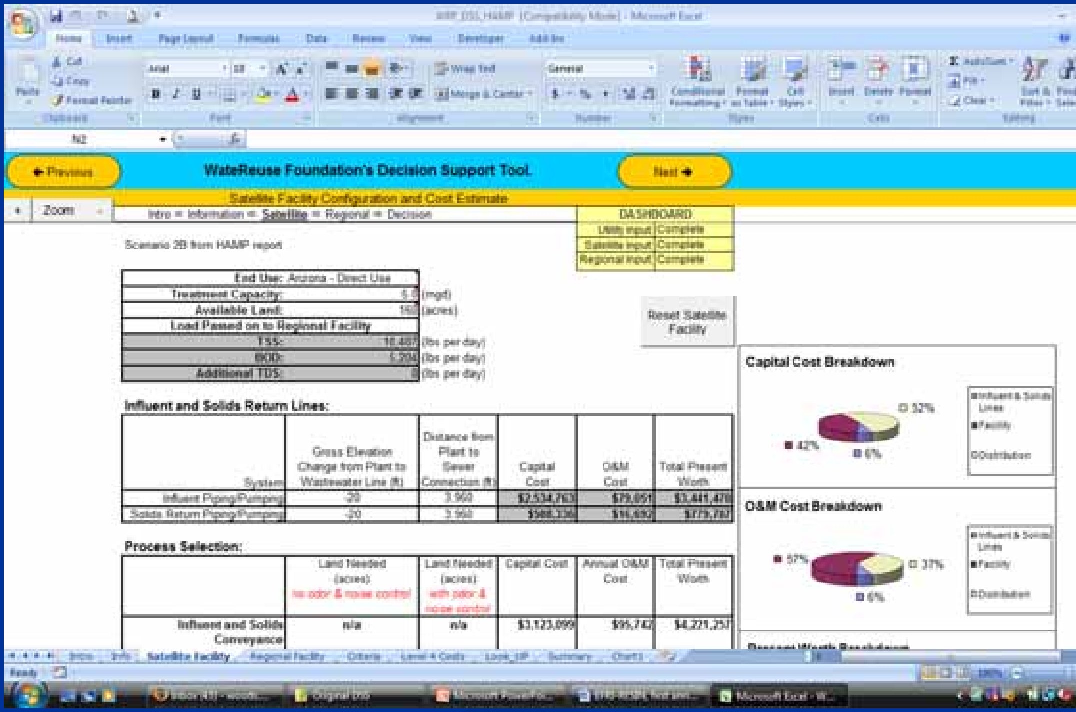
Scott

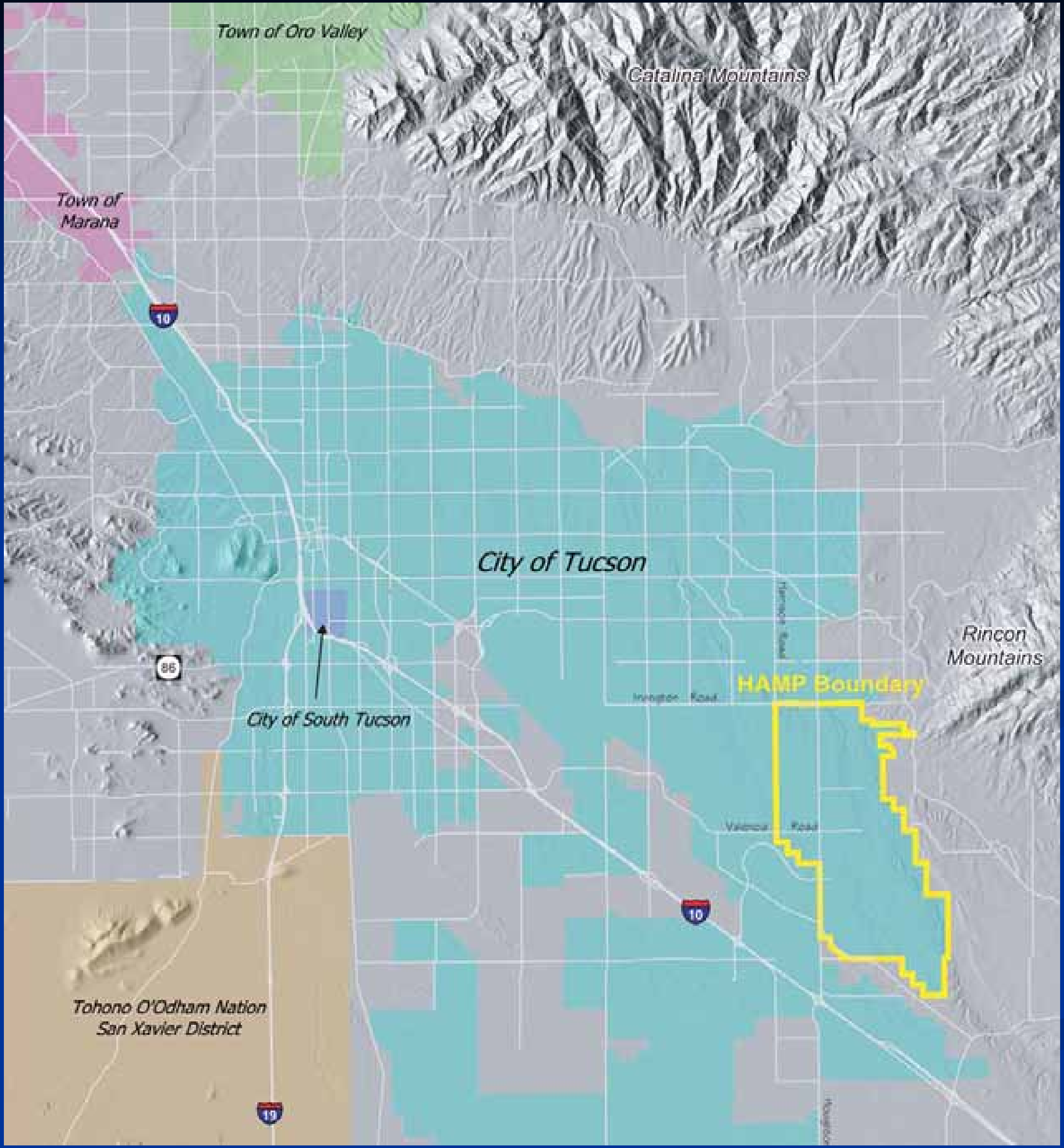
# Economies of Scale vs Pumping Cost



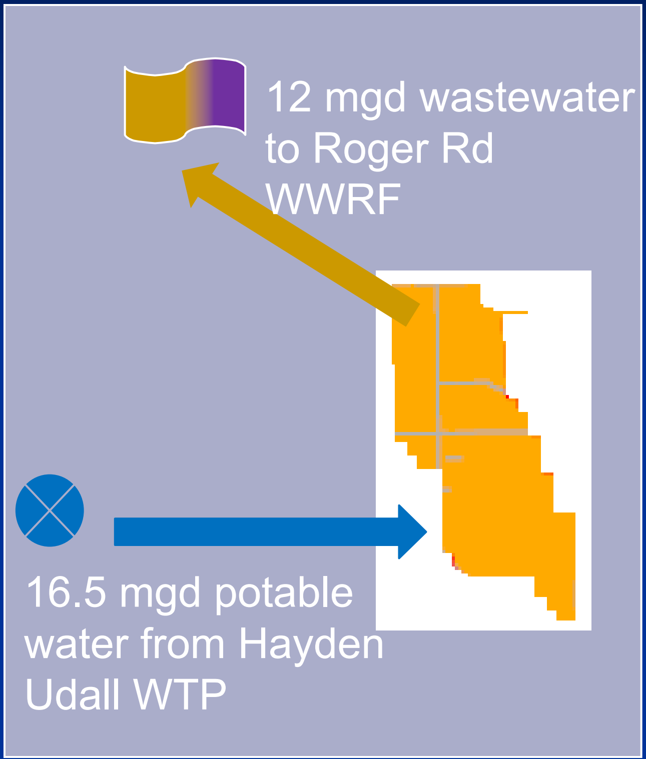
# Decision Support System (DSS)

- Malcolm Pirnie, Inc. under WateReuse Foundation project
- Can compares regional and satellite treatment
- Costs
  - wastewater treatment
  - distribution +/or recharge of reclaimed water
- Other criteria (e.g., reliability, environmental factors) in a weighted decision matrix
- Will be linked with education and optimization tools

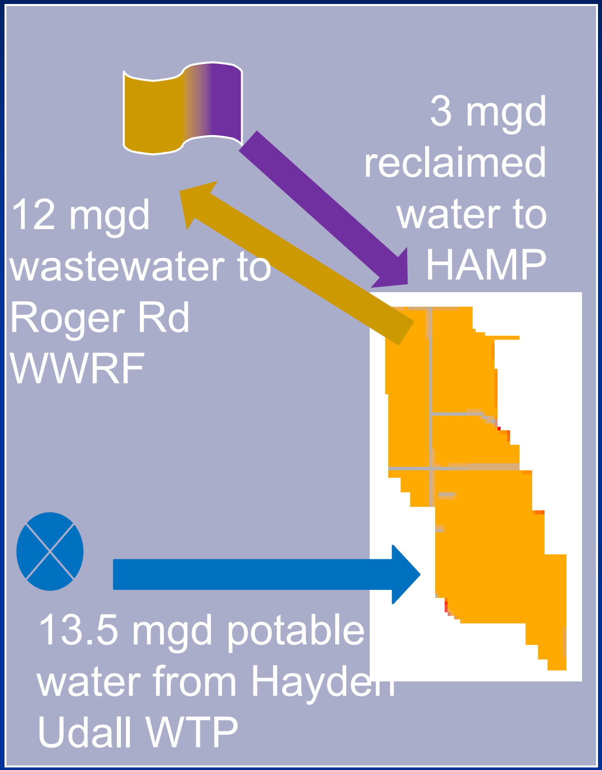



Town of Oro Valley
Catalina Mountains
Town of Marana
10
City of Tucson
86
City of South Tucson
Rincon Mountains
HAMP Boundary
Irvington Road
Valencia Road
10
Tohono O'Odham Nation San Xavier District
19

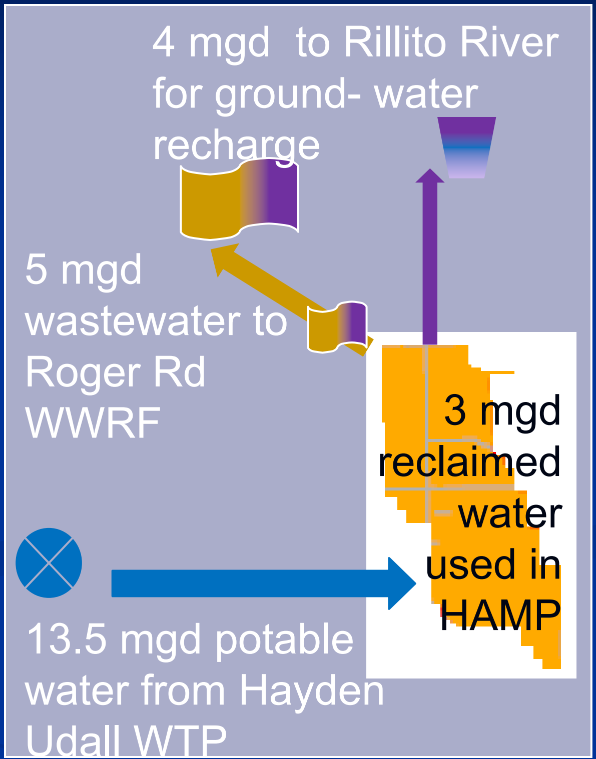
# HAMP Reclamation Scenarios




Scenario 1:
No Reclamation




Regional
Reclamation




Satellite
Reclamation and
Groundwater
Recharge

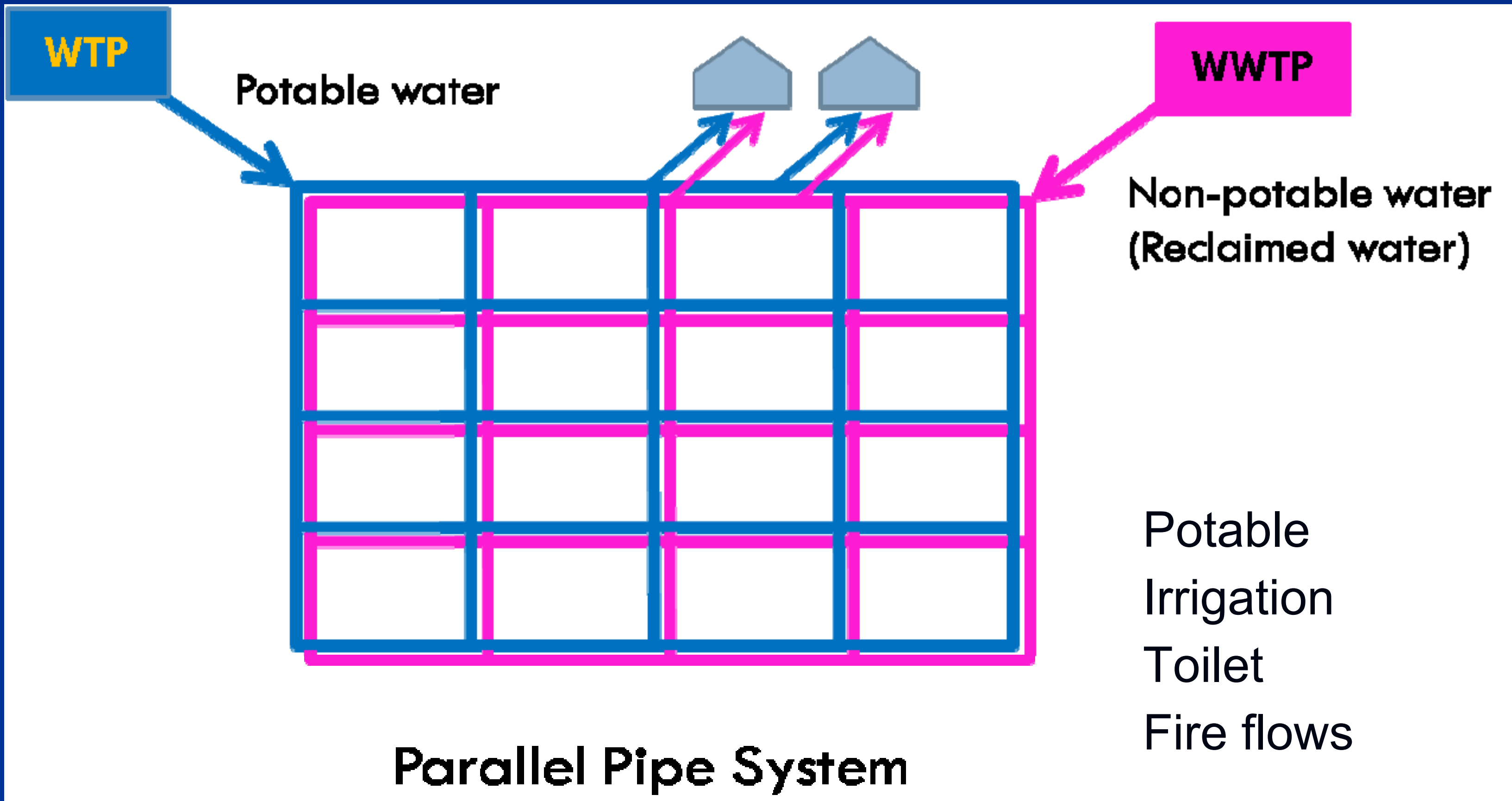
# HAMP Scenarios: Results

| Scenario | Potable System Cost | Wastewater/ Reclaimed System Cost | Total Cost (20 year present worth) |
|---|---|---|---|
| No reclamation | $840 million | $180 million | $1020 million |
| Regional reclamation | $590 million | $230 million | $820 million |
| Satellite reclamation | $590 million | $205 million | $795 million |

- If groundwater recharge is valued at $1000/ acre ft, the recharge option is worth $4.7 million annually.
- Assumptions :
  - New supply line from WTP (versus expansion of existing lines)
  - Neglect expansion of WW collection system
  - Neglect expansion of reclaimed water pipeline

# Dual distribution systems

## What flow to provide through each system?

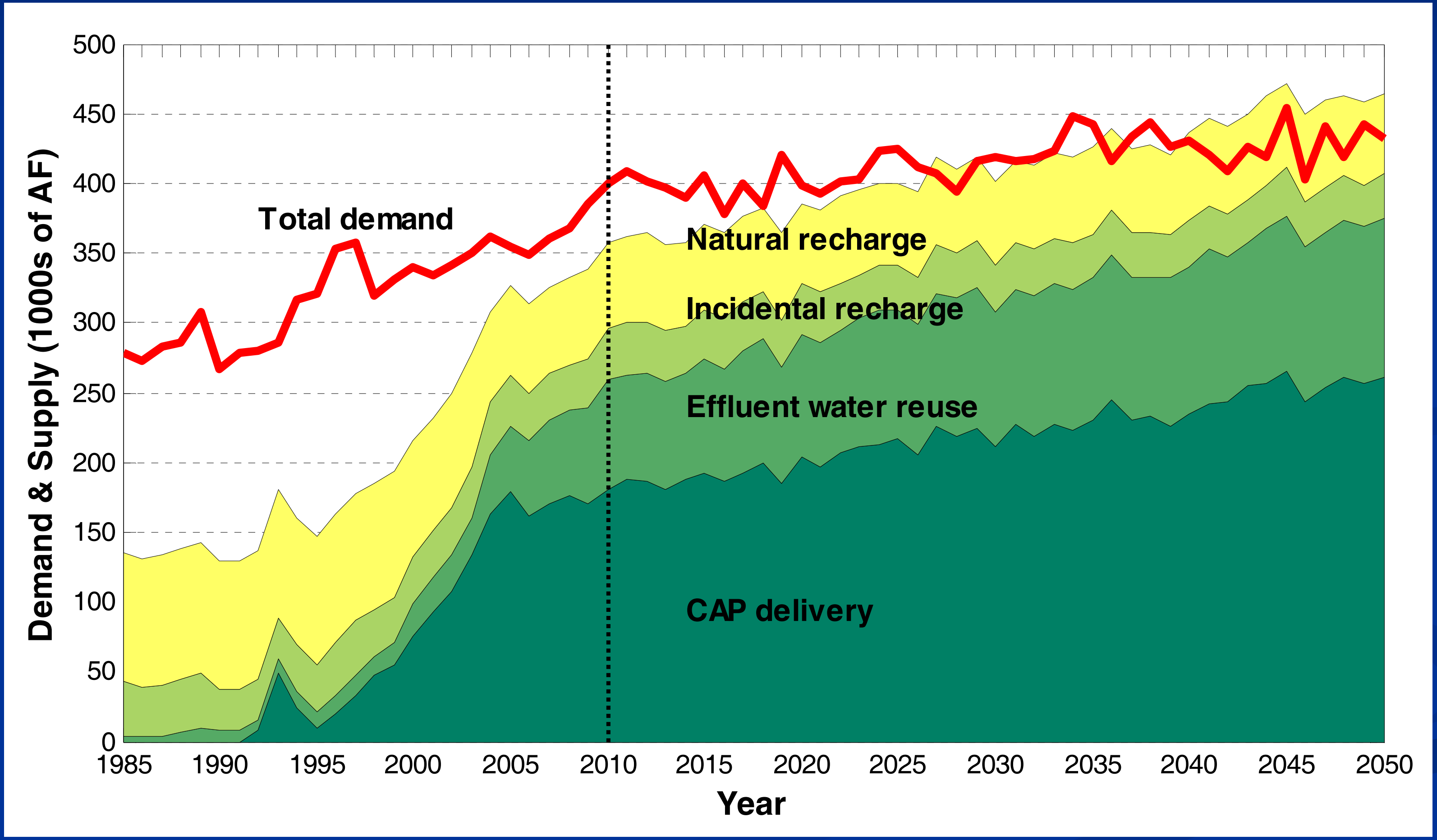



Potable
Irrigation
Toilet
Fire flows

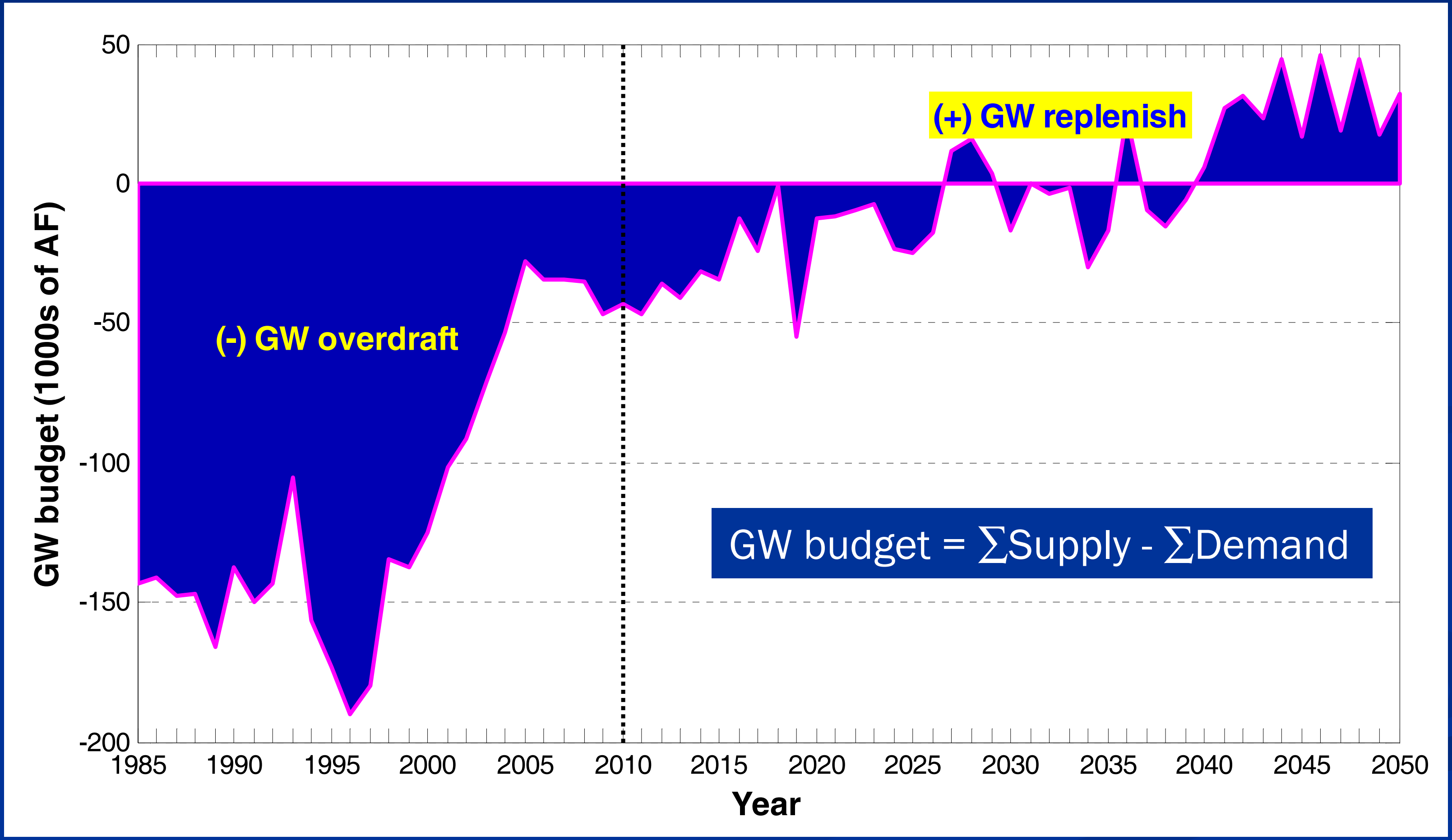
# Optimal cost comparison (minimize costs: pump/pipes/O&M)

| Water use | Scenario 1 | | Scenario 2 | | Scenario 3 | | Scenario 4 | |
|---|---|---|---|---|---|---|---|---|
| | P* | NP** | P | NP | P | NP | P | NP |
| Drinking | | | | | | | | |
| Toilet | | | | | | | | |
| Outdoor | | | | | | | | |
| Fire | | | | | | | | |
| Individual System Cost ($) | 2,507,245 | -- | 1,752,069 | 1,175,731 | 1,650,095 | 1,438,153 | 930,774 | 1,970,812 |
| Total Cost ($) | **2,507,245** | | **2,927,799 (↑ 16.8%)** | | **3,088,246 (↑ 23.2%)** | | **2,901,584 (↑ 15.7%)** | |

# Historical and Projected Demand & Supply



# Historical and Projected GW budgets



# Sustainability Measures (using GW budgets)

1. Reliability (1 - *failure frequency*): R1

   *No. of satisfactory values / Total no. of simulation periods*

2. Resiliency (*failure duration*): R2

   1 / Average duration of unsatisfactory events

3. Vulnerability (*magnitude of failure*): R3

   1 – (Sum of individual unsatisfactory values / Max. among all alternatives)

4. Restorability (*magnitude of success*): R4

   Sum of individual satisfactory values / Max. among all alternatives

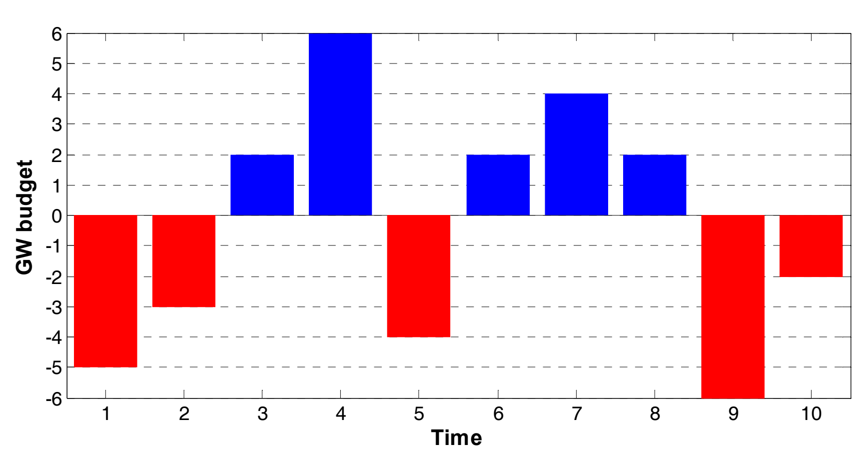
Sustainability Index (*weighted average of R1~R4*)

W1*R1 + W2*R2 + W3*R3 + W4*R4, where W1+W2+W3+W4=1

Note) All measures range [0, 1]

Zero(0) for least sustainable and One(1) for most sustainable condition

# Sustainability Measures (Illustrative example)




R1(reliability) = 5 / 10 = 0.5

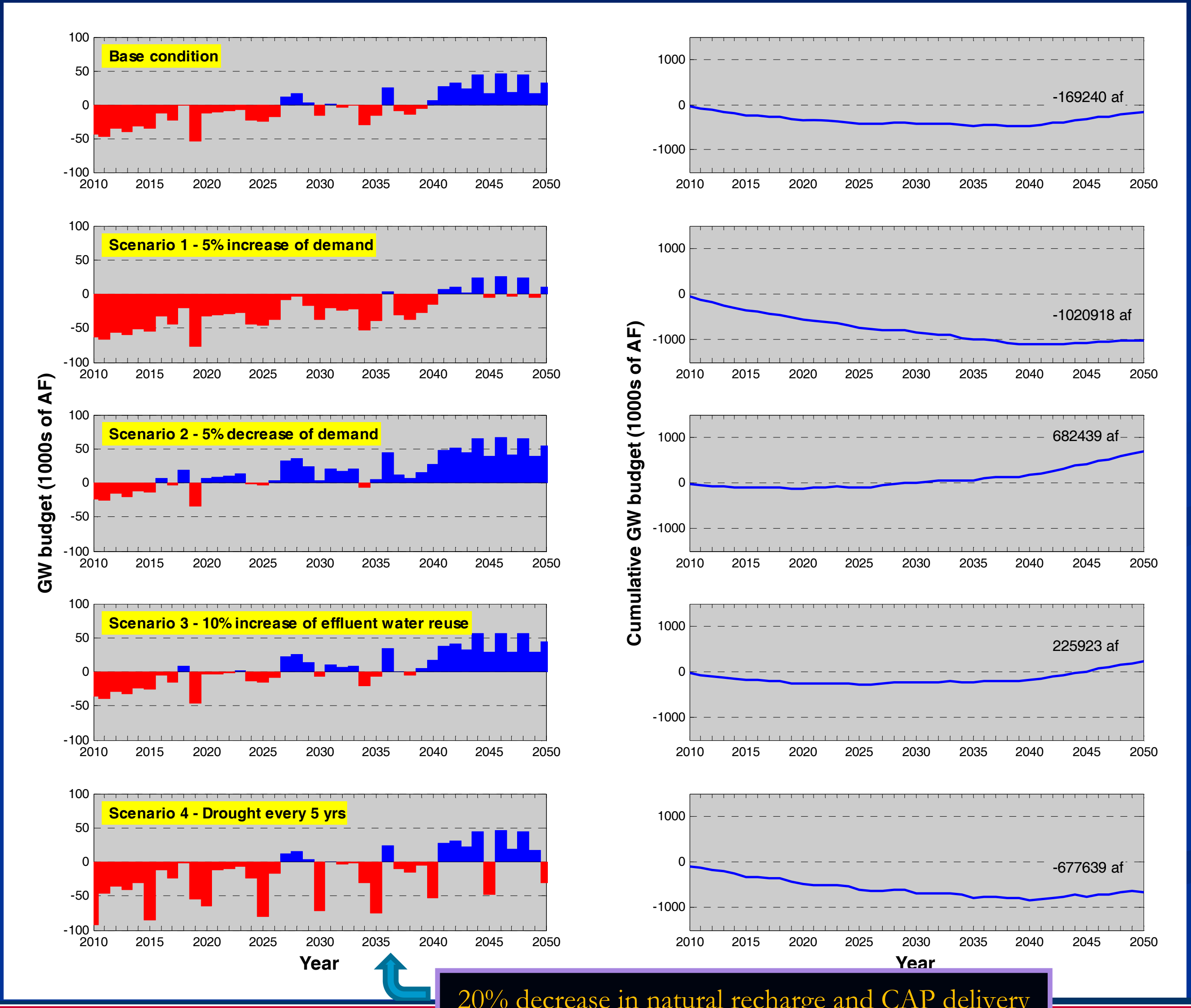
R2(resiliency) = 1 / ((2+1+2)/3) = 0.6

R3(vulnerability) = 1 – (20/25) = 0.2 (*20=5+3+4+6+2, Alter2=25, Alter3=15)

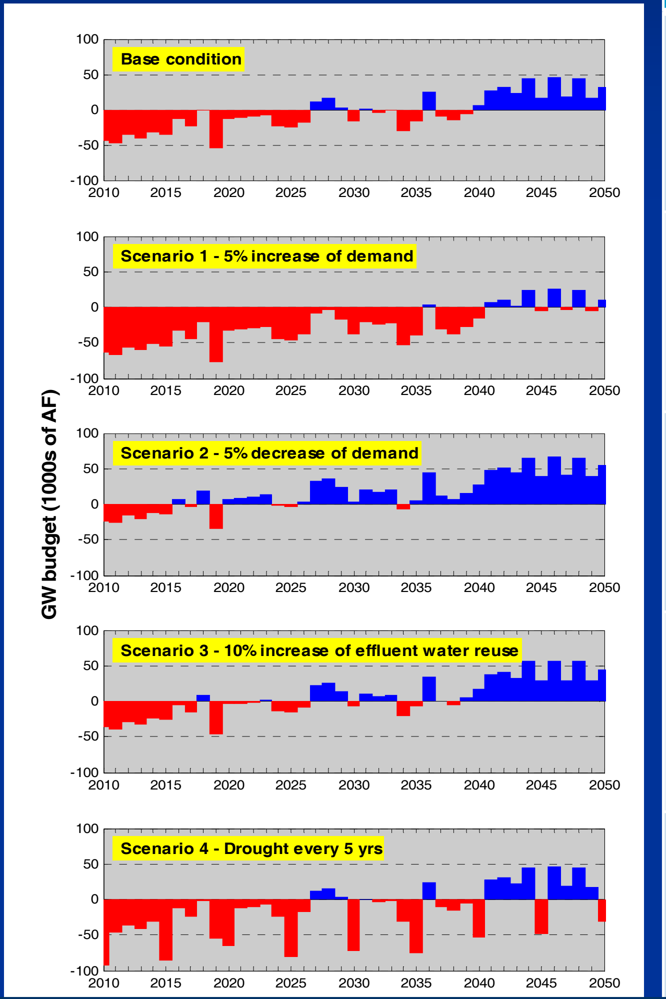
R4(restorability) = 16/23 = 0.7 (*16=2+6+2+4+2, Alter2=14, Alter3=23)

Sustainability = (R1+R2+R3+R4)/4 = 0.5

# Scenario Analysis of the TAMA GW budgets



# Sustainability Measures



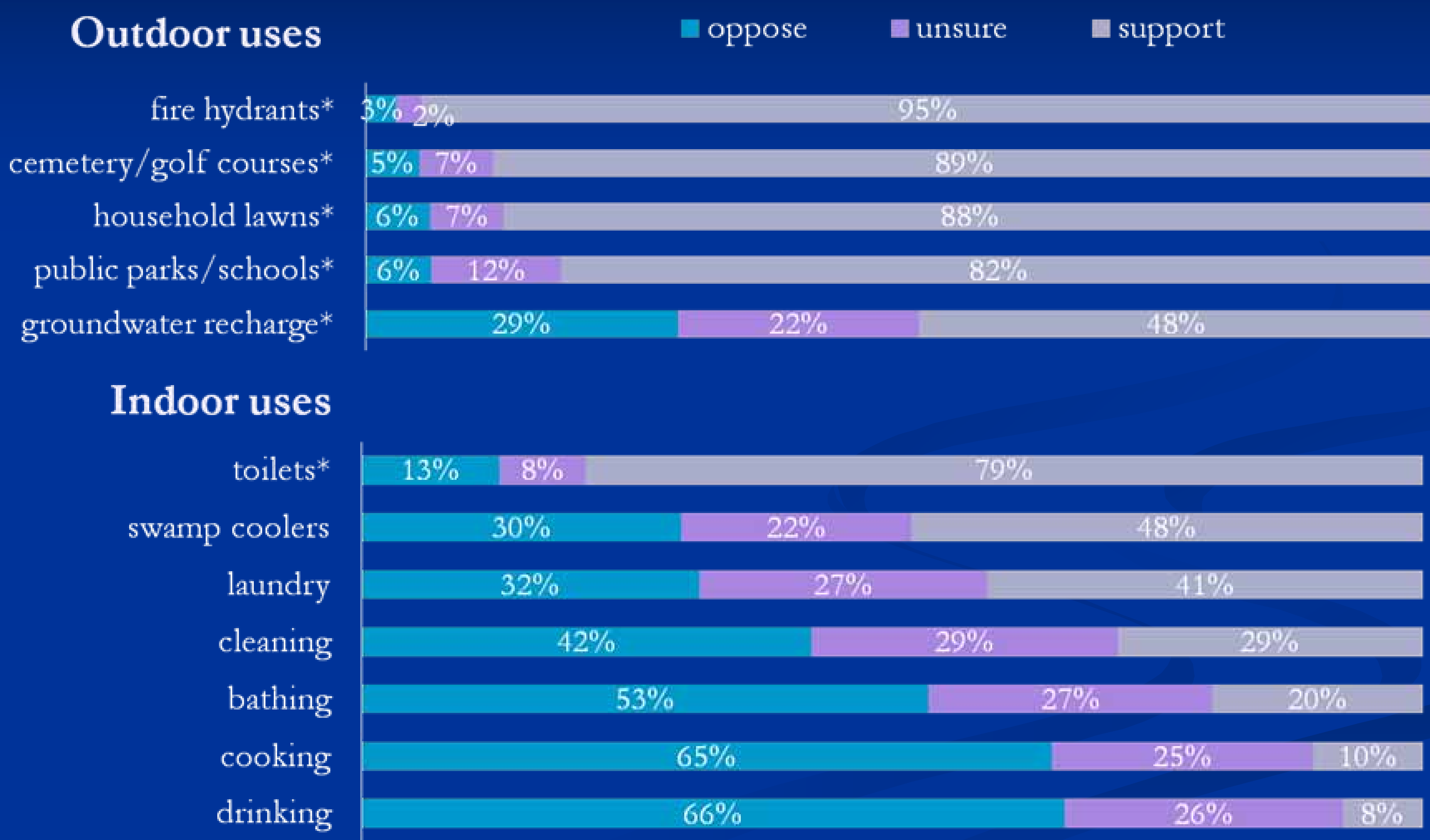

| | Reliability (R1) | Resiliency (R2) | Vulnerability (R3) | Restorab-ility (R4) | Sustain-ability |
|---|---|---|---|---|---|
| Base Condition | 0.39 | 0.16 | 0.53 | 0.43 | **0.38** |
| Scenario 1 | 0.20 | 0.15 | 0.00 | 0.13 | **0.12 (↓0.26)** |
| Scenario 2 | 0.73 | 0.45 | 0.85 | 1.00 | **0.76 (↑0.38)** |
| Scenario 3 | 0.54 | 0.32 | 0.70 | 0.67 | **0.55 (↑0.17)** |
| Scenario 4 | 0.32 | 0.21 | 0.13 | 0.36 | **0.26 (↓0.12)** |

# Design Uncertainties

| **Scale: Temporal→ Spatial ↓** | **Operational (months to several years)** | **Strategic (10 – 100 years)** |
|---|---|---|
| **Conventional system** (independent supply, reuse) | • Mechanical performance<br>• Supply disruptions | • Capacity exceedance<br>• Excess/wasted reclaimed water |
| **Conjunctive system** (with decentralized treatment) | • Conjunctive operations<br>• Financing issues<br>• Regulatory compliance (water quality, $CO_2$ emissions caps) | • Technical obsolescence<br>• Community growth<br>• Water resource variability<br>• Public perceptions of reuse and decentralized treatment |
| **Water resources system** | • Proportions from multiple sources (groundwater, imported, reclaimed)<br>• Quality blend issues | • Climate change<br>• Drought |

Uncertainties affecting
conjunctive system sustainability and resilience

# Tucson general survey -- acceptable urban uses




*Approved uses for reclaimed water per Arizona Administrative Code

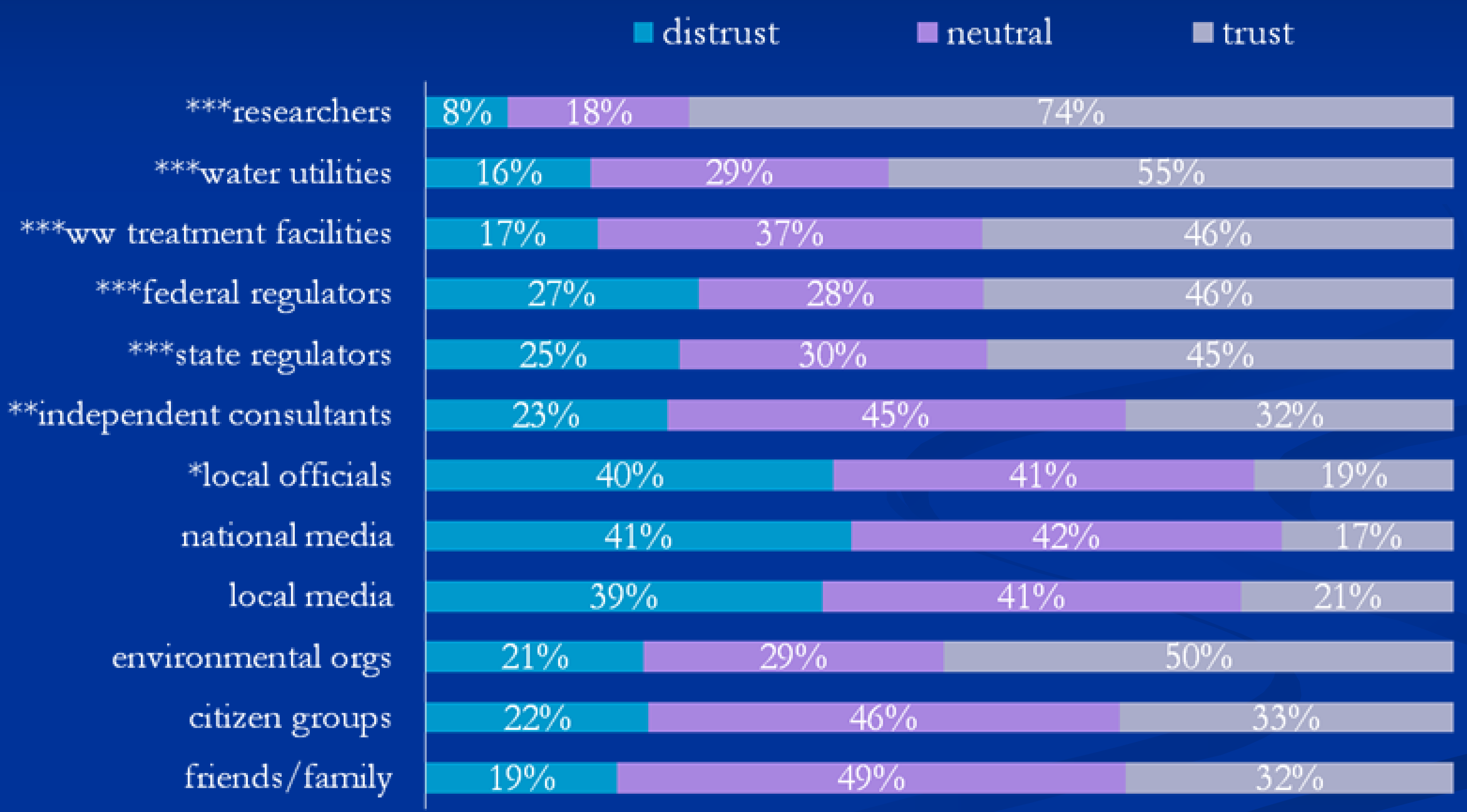
# Existing residential reclaimed water users' acceptance of potential reclaimed water uses

| Reclaimed Water User Study (General) | % Agree/ strongly agree | % Disagree/ strongly disagree | % Unsure |
|---|---|---|---|
| groundwater replenishment | 75/(48) | 11/(29) | 14/(22) |
| swamp coolers | 51/(48) | 28/(30) | 21/(22) |
| laundry | 35/(41) | 45/(32) | 21/(27) |
| toilet | 84/(79) | 14/(13) | 3/(8) |
| swimming | 32/ (*) | 50/ (*) | 22/ (*) |
| car washing | 78/ (*) | 15/ (*) | 7/ (*) |
| cooking | 14/(10) | 68/(65) | 19/(25) |
| drinking | 11/(8) | 70/(66) | 18/(26) |

Values in parens are from the Tucson general survey

# Tucson general survey -- acceptable urban uses

Who do you trust to provide accurate information about reclaimed water?



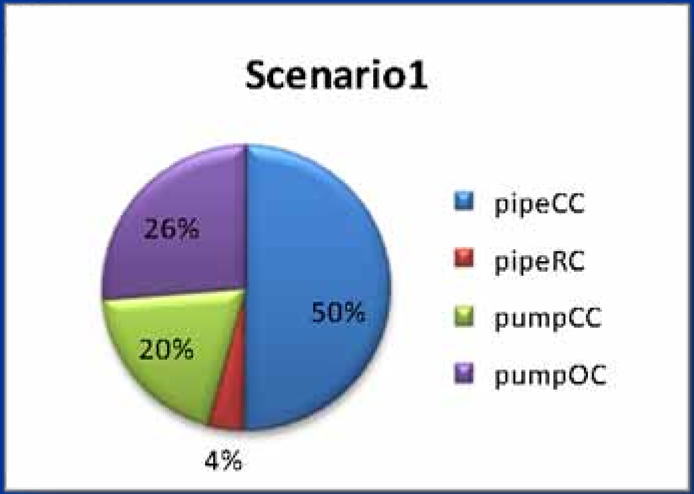

Dependent variable : Would you be willing to drink reclaimed water if it was treated to a water quality level that matched or exceeded your current tap water quality?

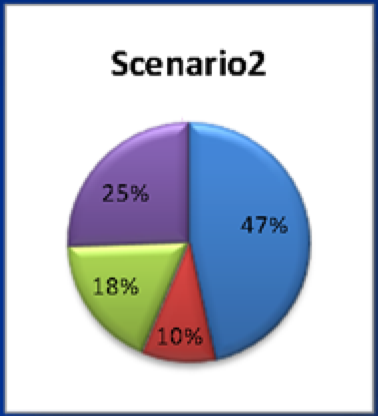
* $p \leq .05$ ** $p \leq .01$ *** $p \leq .001$

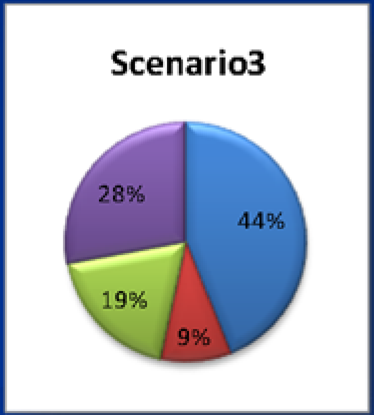
# Aspects of project that will enable potentially transformative results

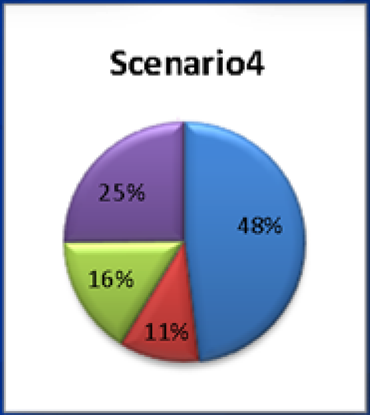
- Demonstrate Water and Wastewater utility collaborations
- Integration of triple bottom line objectives in particular social/institutional
- Education of water needs and policy impact – facilitated public involvement in water/wastewater decisions
- Combining regional water supply planning with detailed distribution system design

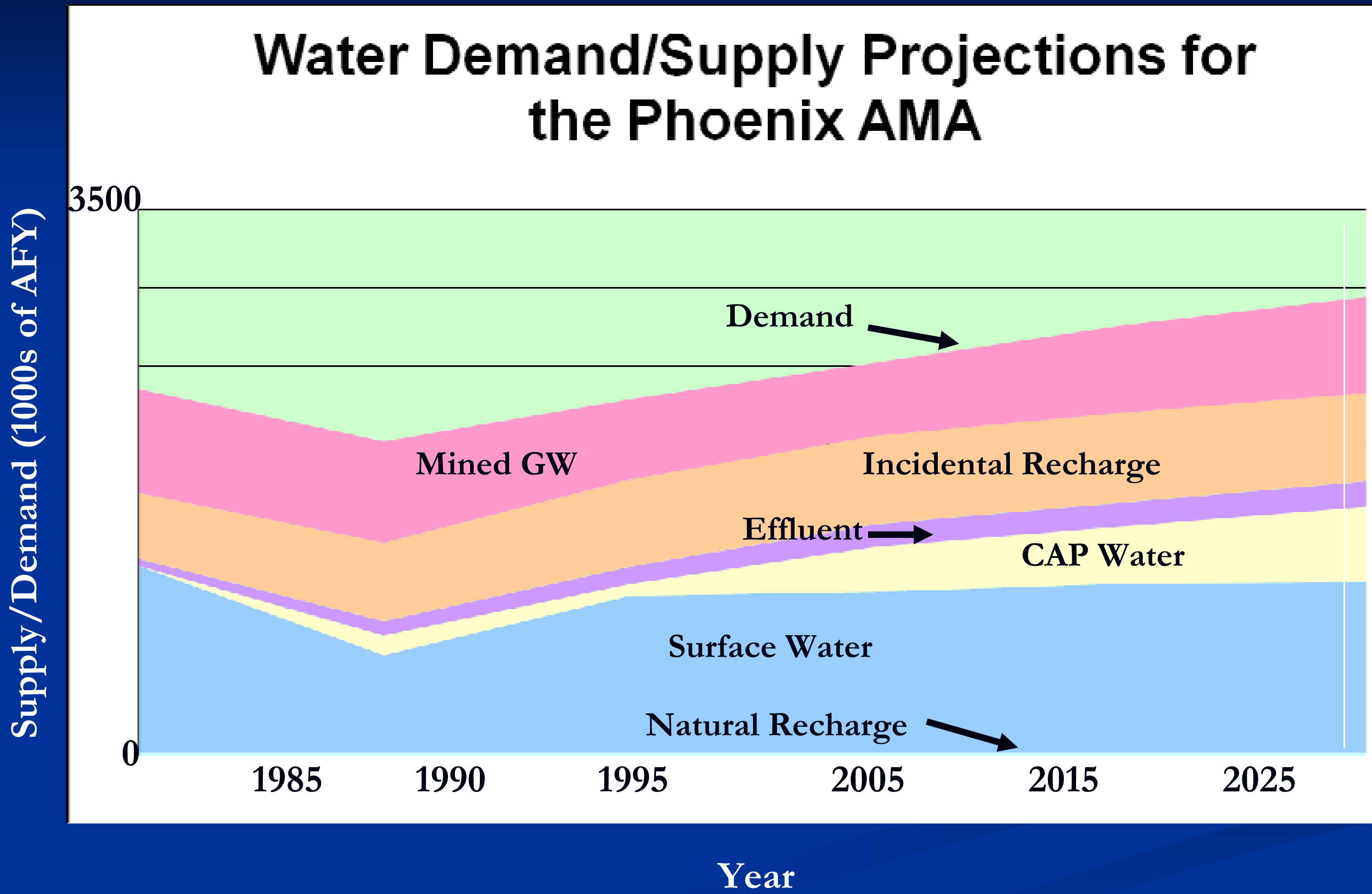
# Economic cost breakdown



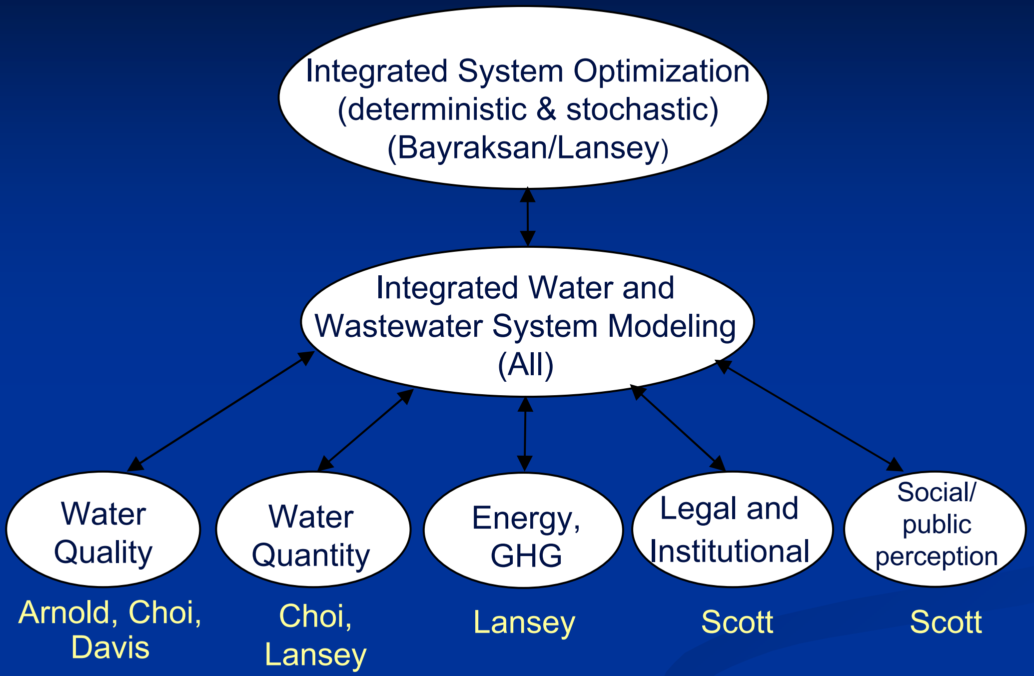





Water Demand/Supply Projections for the Phoenix AMA
3500
0
Supply/Demand (1000s of AFY)
Demand
Mined GW
Incidental Recharge
Effluent
CAP Water
Surface Water
Natural Recharge
1985
1990
1995
2005
2015
2025
Year

# Project Responsibilities




- Monthly full team meetings
- Bi-weekly/weekly sub-group meetings
- Regular partner interactions
- Annual partner summary meetings
- Eight grad students; plans for 2 more with undergraduates

# EFRI-RESIN: Optimization of conjunctive water supply and reuse systems with distributed treatment for high-growth water-scarce regions

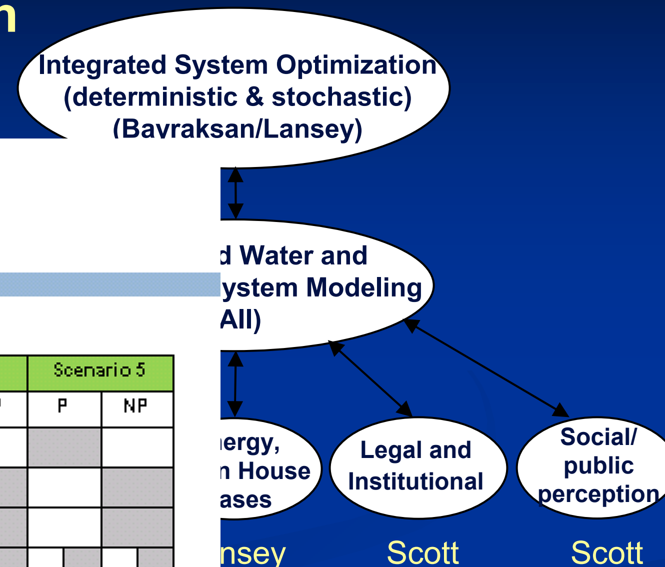
## Rationale

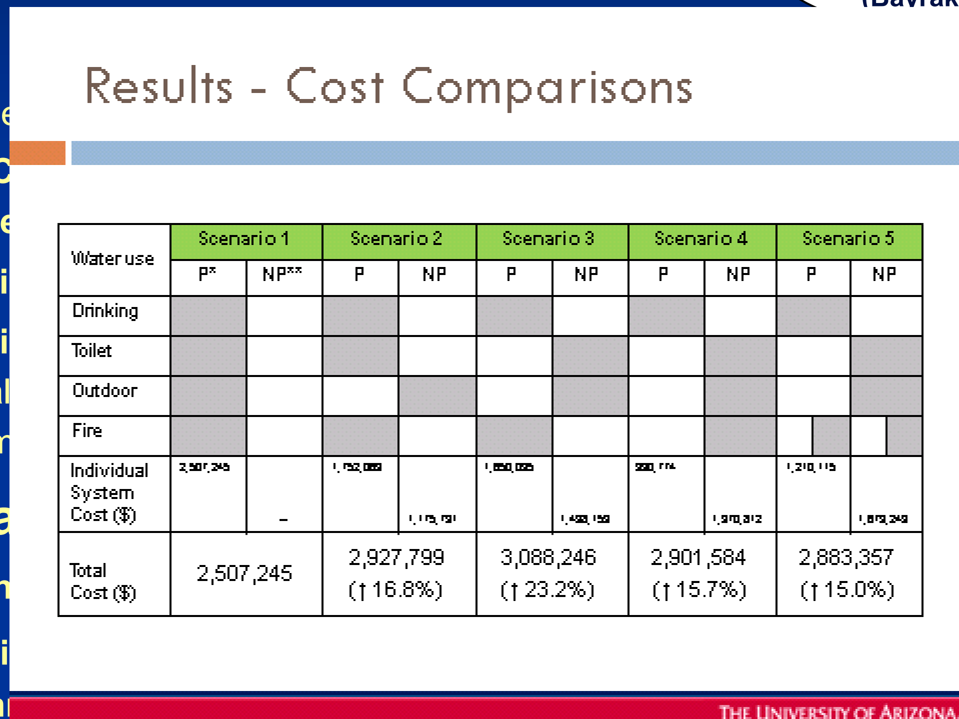
- **Water scarcity – 36 states within 5 years**
- **Key infrastructures:**
  - (i) Water supply
  - (ii) Wastewater treatme
- **NAE grand challenge: "C of urban water and waste**
- **Cost, environment, publi**
- **Resilience & sustainabili**
  - Short term – mechanical
  - Long term – growth, clim

## Impa

- **Paradigm shift to resilien**
- **Optimal design & operati Bottom Line ($$, environ**
- **Decentralized treatment reduces energy & operations costs, increases water reuse**
- **Non-engineering roadblocks to reuse addressed**
- **Applications (real + generic) lead to new insights**

## Approach



Results - Cost Comparisons

| Water use | Scenario 1 | | Scenario 2 | | Scenario 3 | | Scenario 4 | | Scenario 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P* | NP** | P | NP | P | NP | P | NP | P | NP |
| Drinking | | | | | | | | | | |
| Toilet | | | | | | | | | | |
| Outdoor | | | | | | | | | | |
| Fire | | | | | | | | | | |
| Individual System Cost ($) | 2,507,245 | – | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Total Cost ($) | 2,507,245 | | 2,927,799 (↑16.8%) | | 3,088,246 (↑23.2%) | | 2,901,584 (↑15.7%) | | 2,883,357 (↑15.0%) | |

THE UNIVERSITY OF ARIZONA.

## inary Team

g & Engr. Mechanics

ironmental Engineering

**Bayraksan - Systems & Industrial Engineering**

**Choi - Agricultural & Biosystems Engineering**

**Scott - Public Policy; Geography & Reg. Devel.**

**Davis - Malcolm Pirnie Consulting Engineers**